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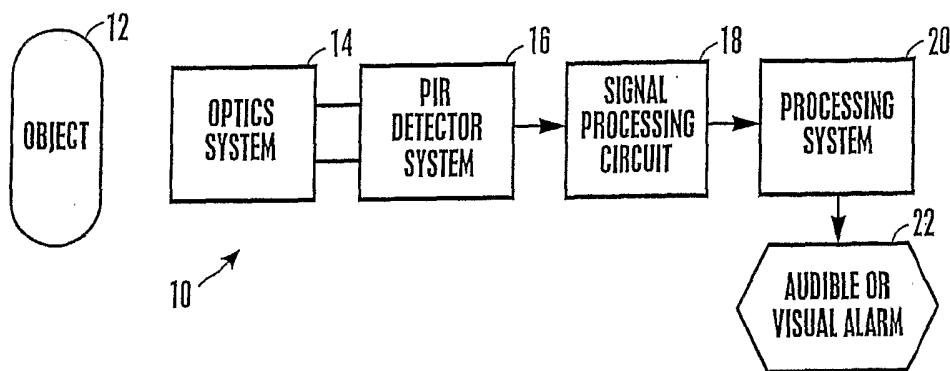
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(54) Title: IMPROVED PIR MOTION SENSOR



(57) Abstract: A passive infrared sensor has two detection members (302/306, 304/308, 316, 318, 320, 322, 324, 328, 330, 332, 334, 336, 338) established by respective detectors and optical elements, with alternating spatial volumes being monitored by each detection member. The detection members are configured such that a moving object causes the members to output different frequencies, whereas a non-moving stimulus produces the same frequency from both detection members. In another aspect, a PIR motion sensor (200) includes first and second elements (202/208, 204/206) generating respective first and second signals that can be added together to render a "sum" signal and subtracted from each other to render a "difference" signal. A moving object is indicated only when the "sum" signal has a frequency different than that of the "difference" signal.

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IMPROVED PIR MOTION SENSOR

I. Field of the Invention

The present invention relates generally to motion sensors.

II. Background of the Invention

The parent applications disclose simple PIR motion sensors with low false alarm rates and minimal processing requirements that are capable of discriminating smaller moving targets, e.g., animals, from larger targets such as humans, so that an alarm will be activated only in the presence of unauthorized humans, not pets.

In USPN 5,923,250, incorporated herein by reference, a motion sensing system is disclosed that uses dead zones between monitored volumes of a space for reducing false alarms caused by small animals. A moving object is indicated not by simultaneous differences in signals between detectors (such as different frequencies), but simply by noting that the detectors alternately produce a temporal sequence of signals as the object moves through the volumes. The present invention recognizes that the principles of the parent applications can be applied with inventive modification to the system disclosed in the '250 patent to obviate the need for dead zones while maintaining functionality.

SUMMARY OF THE INVENTION

In the invention's first aspect, the improved sensor's opto-electronic system produces signals of two different frequencies in response to human motion. The system produces only single-frequency signals, however, in response to detector-interfering stimuli such as white light, shock, temperature change, radio-frequency electromagnetic radiation, etc. Signals are sent to the sensor's signal processing system, which uses the presence or absence of two frequencies to discriminate between moving objects and non-moving interfering stimuli. Thus, the improved sensor has a lower probability of indicating motion that is not in response to a moving object, but to an interfering stimulus. This would be called a "false alarm" in the case of motion sensors used to detect human intruders. Moreover, the sensor can determine direction of motion by evaluating waveform peak juxtapositions between the two different-frequency signals so that the sensor can be used, for example, to open a door only if a human is approaching it from a particular direction.

In the invention's second aspect, the improved sensor's opto-electronic system produces multiple signals from a two-dimensional array of sub-volumes within the space monitored by the sensor. The sensor's signal processing system uses those signals as information regarding size of the moving target, facilitating rejection of signals due to non-human (e.g. small animal) motion. If desired, both aspects can be combined to yield a sensor improved in all three areas mentioned.

Accordingly, in a first aspect a passive infrared (IR) motion sensor includes a first IR detector that outputs a first signal which has a first frequency when a moving object passes in a detection volume of the first detector. A second IR detector outputs a second signal that has a second frequency when the moving object passes in a detection volume of the second detector, and a processing system receives the first and second signals and outputs a detection signal representative of the moving object.

In a preferred embodiment, each detector includes at least two elements, with the elements of the first detector defining a first center-to-center spacing between themselves and the elements of the second detector defining a second center-to-center spacing between themselves. This can be achieved by making the elements of the first detector a different size than those of the second detector, and/or by configuring the first detector to have a different number of elements than the second detector.

In one non-limiting embodiment, the first and second detectors are disposed on a common substrate in a single housing. In another embodiment, the first and second detectors are housed separately from each other and the first detector monitors a first volume of space that is at least partially optically superposed with a second volume of space monitored by the second detector.

In preferred embodiments the first detector can have at least two rows of elements with at least two elements per row, and the second detector can have at least two rows of elements with at least two elements per row. A subvolume monitored by the first detector is at least partially optically superposed on a subvolume monitored by the second detector.

In another aspect, a method for discriminating a moving object in a monitored space from a non-moving object characterized by non-constant radiation includes receiving a first frequency from a first passive IR detector, and receiving a second frequency from a second

passive IR detector, with the first and second frequencies not being equal. The method also includes outputting a signal indicating the presence of the moving object only if both the first and second frequencies are substantially simultaneously received. Otherwise, the signal indicating the presence of the moving object is not output.

In yet another aspect, a processing system is connected to first and second PIR detectors for outputting a detection signal only if signals received from both detectors have different frequencies from each other.

In still another aspect, a motion sensor includes a first passive IR detector having at least two rows of elements with at least two elements per row. The first passive IR detector monitors a first subvolume of space. A second passive IR detector has at least two rows of elements with at least two elements per row, and the second passive IR detector monitors a second subvolume of space. An optics system at least partially optically superposes the first and second subvolumes.

In preferred implementations of this aspect, the first IR detector outputs a first signal representative of a point or points in a first dimension and the second IR detector outputs a second signal representative of a point or points in a second dimension. The first dimension can be an x-dimension in a Cartesian coordinate system and the second dimension can be a y-dimension in the Cartesian coordinate system. Or, the dimensions can be orthogonal dimensions such as "r" and " θ " in polar coordinates.

The signals can represent plus and minus polarities, and a processor can use the polarities to determine direction of motion of an object. Also, the processor can determine active coordinates using the signals to determine at least a size of a moving object. Specifically, the processor can determine whether a number of simultaneously active coordinates is equal to a threshold and based thereon determine whether to activate an alarm.

In another aspect, a PIR sensor includes a first detector configured for outputting signals that represent at least one of at least two points along a first dimension. The first detector receives IR radiation from a first monitored sub-volume of space. A second detector is configured for outputting signals that represent at least one of at least two points along a second dimension different from the first dimension, with the second detector

receiving IR radiation from a second monitored sub-volume of space that at least partially overlaps the first monitored sub-volume of space.

In an alternate embodiment a passive infrared (IR) motion sensor has a first IR detector outputting a first signal having a first frequency when a moving object passes in a detection volume of the first detector, and a second IR detector outputting a second signal having a second frequency when the moving object passes in a detection volume of the second detector, with the second frequency being different than the first. A processing system receives the first and second signals and based thereon outputs a detection signal representative of the moving object. The detectors have the same size as each other, with the first detector being provided with a first optics defining a first focal length and the second detector being provided with a second optics defining a second focal length different than the first focal length.

If desired, the first and second detectors may be housed separately from each other. In a non-limiting embodiment, each detector has two and only two respective elements with the elements being of equal size with each other and with the spacing between the elements of the first detector being the same as the spacing between the elements of the second detector.

In another aspect of this last-mentioned embodiment, a method for discriminating a moving object in a monitored space from a non-moving object characterized by non-constant radiation includes receiving a first frequency from a first passive IR detector, receiving a second frequency from a second passive IR detector, with the first and second frequencies not being equal. The detectors are of equal size and configuration but have respective optics of different focal lengths. The method includes outputting a signal indicating the presence of the moving object only if both the first and second frequencies are substantially simultaneously received, and otherwise not outputting the signal indicating the presence of the moving object.

In another aspect, a motion sensor includes a first passive IR detector having two and only two elements defining a first spacing therebetween. The first passive IR detector monitors a first subvolume of space. A second passive IR detector has two and only two elements defining a second spacing therebetween. The second spacing is equal to the first

spacing and all four elements have the same size as each other. The second passive IR detector monitors a second subvolume of space. An optics system at least partially optically superposes the first and second subvolumes. The optics system defines a first focal length associated with the first detector and a second focal length associated with the second detector. The first and second focal lengths are not equal to each other.

In another implementation, a PIR motion sensor includes an infrared detector having at least first and second elements generating respective first and second signals. Each element includes a first part and a second part. A system adds the first and second signals together to render a "sum" signal. The system also subtracts one signal from the other to render a "difference" signal. The system outputs a detection signal representative of a moving object when the "sum" signal has a frequency different than that of the "difference" signal, and otherwise does not output the detection signal.

The first element may monitor a first volume of space that may be optically superposed or interposed with a second volume of space monitored by the second element. Each element may have two and only two respective positive and negative parts, with the parts being of equal size with each other. If desired, the positive parts can be physically next to each other without any negative parts intervening and the negative parts can be physically next to each other without any positive parts intervening. In a non-limiting implementation the parts are arranged in a line on a substrate in the following order: a positive part of the first element, a positive part of the second element, a negative part of the second element, and a negative part of the first element. The parts of an element are electrically connected to each other.

In another aspect of this latter implementation, a method for discriminating a moving object in a monitored space from a non-moving object characterized by non-constant radiation includes providing first and second detector elements that generate respective first and second signals. The method also includes adding the signals together to render a "sum" signal, as well as subtracting one signal from the other to render a "difference" signal. A moving object is indicated if the "sum" signal has a frequency that is different from the frequency of the "difference" signal, and otherwise a moving object is not indicated.

In yet another aspect of this latter implementation, a motion sensor includes a first passive IR detector element having two and only two parts and monitoring a first subvolume of space, and a second passive IR detector element similarly having two and only two parts and monitoring a second subvolume of space. An optics system may optically interpose or superpose the first and second subvolumes. The motion sensor has a system that indicates a moving object only if a frequency of the difference between signals generated by the elements is different from a frequency of the sum of the signals generated by the elements.

In yet another embodiment a PIR motion sensor includes at least first and second infrared detection members, with each detection member including at least one optical element and at least one detector with at least positive and negative detector elements. The optical elements cooperate to establish four or more monitored spatial volumes substantially without any unmonitored dead space between any two adjacent volumes. The first detection member monitors first volumes and the second detection member monitors second volumes, and the first and second volumes spatially alternate in sequence. A moving object causes the detector of the first detection member to output a signal having a frequency that is different from an output of the detector of the second detection member, while a non-moving stimulus causes both detectors to output the same frequency.

To produce this frequency discrimination of moving objects from non-moving stimuli, detector elements of the first detection member can have different sizes than detector elements of the second detection member. In addition or alternatively, the spacing between adjacent detector elements of the first detection member can be different from the spacing between adjacent detector elements of the second detection member. Or, the focal length of the optical element of the first detection member may be different from the focal length of the optical element of the second detection member. As yet another way to produce frequency-based discrimination of moving objects from non-moving stimuli, the number of lens elements of the optical element of the first detection member can be different from the number of lens elements of the optical element of the second detection member.

In another aspect of this additional embodiment, a motion sensor has at least first and second detection members monitoring alternating volumes of space with substantially no unmonitored vertical space between any two monitored volumes. Each detection member includes at least one optical element and at least one detector with at least positive and negative detector elements, and a moving object causes the detection members to output different frequencies from each other whereas a non-moving stimulus causes both detection members to output the same frequency.

In yet another aspect, a motion sensor has at least first and second detection members monitoring alternating volumes of space. Each detection member includes at least one optical element and at least one detector with at least positive and negative detector elements, and a moving object causes the detection members to output different frequencies from each other, whereas a non-moving stimulus causes both detection members to output the same frequency.

In another aspect, a motion sensor has at least first and second detection members monitoring alternating volumes of space with substantially no unmonitored vertical space between any two monitored volumes. Each detection member includes at least one optical element and at least one PIR detector with at least positive and negative detector elements

The details of the present invention, both as to its structure and operation, can best be understood in reference to the accompanying drawings, in which like reference numerals refer to like parts, and in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of the present system architecture;

Figure 2 is a schematic diagram of a first sensor embodiment with differently-sized detectors on the same substrate in one housing, showing a plan view of the detectors along with symbol and functional diagrams of the sensor;

Figure 3 is a schematic diagram of a second sensor embodiment with two detectors in separate housings, showing a plan view of the detectors along with symbol and functional diagrams of the sensor;

Figure 3a is a schematic diagram of an alternate embodiment of the second sensor embodiment shown in Figure 3 that achieves the same functional diagram but that has

equally-sized detectors with optics of different focal lengths, showing a plan view of the detectors along with symbol diagrams of the sensor;

Figure 4 are graphs of signals generated by the sensors of Figures 2 and 3;

Figure 5 is a schematic diagram of a third sensor embodiment with detectors in separate housings wired in orthogonal dimensions, showing a plan view of the detectors, along with symbol and functional diagrams of the sensor;

Figure 6 is a schematic diagram of another implementation of the third sensor embodiment with detectors in separate housings wired in orthogonal dimensions, showing a plan view of the detectors, along with symbol and functional diagrams of the sensor;

Figure 7 is a schematic diagram of a fourth sensor embodiment with differently-sized detectors in separate housings wired in orthogonal dimensions, showing a plan view of the detectors, along with symbol and functional diagrams of the sensor;

Figure 8 is a schematic diagram of another implementation of the fourth sensor embodiment with differently-sized detectors in separate housings wired in orthogonal dimensions, showing a plan view of the detectors along with symbol and functional diagrams of the sensor;

Figure 9 is a schematic diagram of still another implementation of the fourth sensor embodiment with differently-sized detectors in separate housings wired in orthogonal dimensions, showing a plan view of the detectors, along with symbol and functional diagrams of the sensor;

Figure 10 is a flow chart of the logic for using plural frequencies to obtain an output representative of a moving object;

Figure 11 is a flow chart of the logic for using the two dimensional sensors of Figures 5-9 to obtain an output representative of a moving object;

Figure 12 is a schematic diagram of still another sensor embodiment showing a plan view of the detectors along with symbol and functional diagrams of the sensor, and showing a human figure schematically;

Figure 13 is a graph of signals generated by the sensor of Figure 12;

Figure 14 is a block diagram of an alternate motion sensor system;

Figure 15 is a schematic diagram showing a side view of monitored spatial volumes; and

Figures 16-21 are schematic diagrams of various embodiments of the system shown in Figure 14, each showing a respective functional diagram (each arising from a detector element plan view as in previous figures) of the various detectors along with a respective symbol diagram.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to Figure 1, a system is shown, generally designated 10, for detecting a moving object 12, such as a human. The system 10 includes an optics system 14 that can include appropriate mirrors, lenses, and other components known in the art for focussing images of the object 12 onto a passive infrared (PIR) detector system 16. The disclosure below discusses various embodiments of the PIR detector system 16. In response to the moving object 12, the PIR detector system 16 generates a signal that can be filtered, amplified, and digitized by a signal processing circuit 18, with a processing system 20 (such as, e.g., a computer or application specific integrated circuit) receiving the signal and determining whether to activate an audible or visual alarm 22 or other output device such as an activation system for a door, etc. in accordance with the flow charts herein.

Having described the overall system architecture, reference is now made to Figure 2, which shows a first exemplary embodiment of the PIR sensor of the present invention. As shown, IR detection means for a PIR sensor 24 can include a single, preferably ceramic substrate 26 on which are formed first and second PIR detectors 28, 30. In the embodiment shown in Figure 2, the first detector 28 has four elements 32 (two pair of plus and minus polarity elements electrically connected together) and the second detector 30 has two elements 34 (one pair of plus and minus polarity elements), with each pair of elements 32, 34 being joined by an electrical connection, roughly forming an "H". It is to be understood that the detectors 28, 30 include, on the reverse side of the substrate 26 from that shown, complementary components (e.g. "plates" as explained below) which, together with those shown, form the elements 32, 34. Connections among these reverse-side plates are depicted by dashed lines.

The detectors 28, 30 can be pyroelectric detectors that measure changes in far infrared radiation. Such detectors operate by the "piezoelectric effect", which causes electrical charge migration in the presence of mechanical strain. Pyroelectric detectors take the form of a capacitor -- two electrically conductive plates separated by a dielectric. The dielectric is often a piezoelectric ceramic, and is referred to herein as a "substrate". When far infrared radiation causes a temperature change (and thus some mechanical strain) in the ceramic, electrical charge migrates from one plate to the other. If no external circuit is connected to the detector, then a voltage appears as the "capacitor" charges. If an external circuit is connected between the plates, then a current flows.

In accordance with present principles, the center-to-center spacing "d1" between adjacent elements 32 of the first detector 28 is less than the center-to-center spacing "d2" between adjacent elements 34 of the second detector 30. This difference can be achieved as shown in Figure 2 by making the elements 34 of the second detector 30 larger than the elements 32 of the first detector 28. It can also be achieved by spacing the second detector elements 34 further apart than the first detector elements 32, and/or by providing fewer second detector elements 34 than first detector elements 32.

Figure 2 also shows a functional diagram of the detectors 28, 30 with elements 32, 34 in accordance with pyroelectric detector principles summarized above, indicating the relative sizes, shapes, and polarities of the subvolumes monitored by the sensor (i.e., a projection of the sizes, shapes, and polarities of the elements) and illustrating that both detectors 28, 30 are mounted in a single housing 35. Also, Figure 2 shows a schematic symbol diagram representing the elements 32, 34 of the detectors 28, 30 as capacitors with the dots indicating polarity.

Figure 3 shows IR detection means for a PIR sensor 35 that has first and second detectors 36, 38 that are in all essential respects identical in configuration to the detectors 28, 30 shown in Figure 2, except that each detector 36, 38 is mounted on its own respective substrate 40, 42. The substrates 40, 42 can be contained in respective housings 44, 46. According to the embodiment shown in Figure 3, the optics system 14 (Figure 1) is arranged such that two preferably dissimilar space sub-volumes are respectively monitored by the detectors 36, 38 and such that the two sub-volumes are optically superposed with

each other behind similar optical components. Essentially, combinations of optical components of compound optics are selected such that both detectors' monitored sub-volumes occupy at least portions of the same space.

In contrast to the embodiment shown in Figure 2, the sensor of Figure 3 produces two signal frequencies regardless of image size, due to complete functional overlapping of unequal-size elements. It thus has less dependence on object size to generate a detection than does the sensor shown in Figure 2, which requires that the object be sufficiently large to appear in both monitored sub-volumes.

Figure 3 also includes a functional diagram illustrating the aspect ratios and juxtaposition of the longitudinal cross-sections of the two sets of monitored sub-volumes. If desired, the two sets of detectors could be wired together to provide a combined signal, which would reduce the number of amplifiers needed in the sensor, at the cost of additional signal processing to separate the two frequencies.

Figure 3a shows an additional detector arrangement that achieves the same functional diagram shown in Figure 3. A PIR sensor 35a has first and second detectors 36a, 38a that are in all essential respects identical in size and configuration to each other, with each detector 36a, 38a being mounted on its own respective substrate 40a, 42a. The substrates 40a, 42a can be contained in respective housings 44a, 46a. Each detector 36a, 38a has two and only two elements (minus and plus) as shown, and all four elements shown in Figure 3a are of equal size, with the spacing between the elements of the first detector 36a being the same as the spacing between the elements of the second detector 38a.

According to the embodiment shown in Figure 3a, the detectors 36a, 38a are provided with respective optics within the optics system 14 that have different focal lengths. In the case where, e.g., the focal length ratio is 2:1, the optics are compound, and the optics associated with the detector 36a can have twice the number of optical elements as the optics associated with the detector 38a. The optics of the detectors 36a, 38a are arranged such that both detectors' monitored sub-volumes occupy at least portions of the same space.

In contrast to the embodiment shown in Figure 2, the sensor of Figure 3 produces two signal frequencies regardless of image size, due to complete functional overlapping of unequal-size elements. It thus has less dependence on object size to generate a detection

than does the sensor shown in Figure 2, which requires that the object be sufficiently large to appear in both monitored sub-volumes.

Figure 4 illustrates the signals that are output by the sensors shown in Figures 2 and 3. For simplicity, reference to the detectors 36, 38 shown in Figure 3 will be made. The top two signals 48, 50 in signal set (a) are output by separate elements of the first detector 36 in the presence of motion of a human through the sub-volumes monitored by the detectors, while the signals 52, 54 in signal set (a) are output by separate elements of the second detector 38 in the presence of a moving human. As shown, the frequency of the element-summed detector output signal 49 is different than (and in the example shown is higher than) the frequency of the element-summed detector output signal 53. When the center-to-center spacings bear a 2:1 ratio, the frequencies of the respective detector output signals likewise bear a 2:1 ratio. Moreover, the first peak of the first detector high frequency signal 49 is substantially simultaneous in time with the maximum positive slope of the second detector low frequency signal 52, in the presence of a moving object. A moving object can be identified by identifying these characteristics (and similar subsequent characteristics of different peak/slope polarity) as being present.

In contrast, signal set (b) represents the detector outputs in response to varying-intensity non-focused white light from a stationary source. These signals arise because the responses of the "equal" and opposite elements only roughly cancel each other. As can be appreciated in reference to Figure 4, under these circumstances the frequencies of the element-summed signal 57 and 61 that are respectively output by the detectors 36, 38 are equal and, hence easily discriminated from the dual-frequency signals in set (a), thereby reducing the probability of false alarms arising from such varying-intensity non-focused white light.

Moreover, from the pattern of signals generated by the two detectors 36, 38, the direction of motion of the human object 12 can be determined from the polarity pattern of the signal waveform peaks. For example, as alluded to above and referring to the functional diagram of Figure 3, a moving object 12 entering the larger (+) monitored sub-volume from its left side causes simultaneously a (+) signal slope from the corresponding detector element, and a (+) signal peak from the element corresponding to the left-hand

(+) smaller overlapping sub-volume. By continuing in the same direction within the larger (+) monitored sub-volume, the target then causes a (+) signal peak from the corresponding detector element. Still continuing, within the same larger (+) monitored sub-volume, the target causes simultaneously a (-) signal slope from the corresponding detector element, and a (-) signal peak from the element corresponding to the right-hand (-) smaller overlapping sub-volume. In the foregoing case, the simultaneous signal slopes and peaks of matching polarity indicate one direction of motion, whereas slopes and peaks of non-matching polarity indicate the opposite direction of motion. Using the above-disclosed signal sequence principles, the direction of object motion can be ascertained.

Now referring to Figure 5, another embodiment of the present improved PIR motion sensor can be seen. As shown, IR detection means for a PIR sensor 64 includes a first detector 66 and a second detector 68. The detectors 66, 68 may be mounted in separate housings. As shown in both the top plan detector view and the schematic symbol diagram, the first detector 66 has two pair of dual-polarity elements 70, 72 that are wired along the x-axis, while the second detector 68 has two pair of dual-polarity elements 74, 76 that are wired along the y-axis. Each pair of dual-polarity elements 70-74 establishes a row of elements. With this configuration, the first detector 66 outputs a signal that is representative of motion in a first dimension (such as, e.g., the y-dimension in a Cartesian system or the radial dimension in a polar system) and the second detector 68 outputs a signal representative of motion in a second dimension (e.g., the x-dimension in a Cartesian system or the angular dimension in a polar system) that is orthogonal to the first dimension.

According to the invention shown in Figure 5, the sub-volumes of space monitored by the detectors 66, 68 are optically superposed by appropriately configuring the optics system 14 (Figure 1). With this arrangement, the sensor 64 shown in Figure 5 establishes a two-dimensional array of pyroelectric detector-monitored sub-volumes that is formed by optical superposition of monitored space sub-volumes resulting from mounting two detectors 66, 68 with orthogonal element wirings behind similar optical components. In other words, the optics system 14 causes both detectors' monitored sub-volumes to occupy the same space, as shown in the functional diagram by the virtual composite detector 78. A moving object can be discriminated from varying intensity white light because movement

causes a succession of signals to be generated across the coordinate system, whereas varying white light does not. Stated differently, a location in two-dimensional space is defined by the simultaneous signals from the detectors 66, 68, and when the signals, over time, indicate a change in coordinates, motion of the object is implied. The processing system simply correlates such changes in coordinates to movement to, e.g., activate the alarm when motion is so detected.

As can be appreciated looking at the virtual composite detector 78 in the functional diagram of Figure 5, by examining the polarities of signals that are simultaneously received from the detectors 66, 68, the position of the object 12 can be determined, in this case, as a confirmation to the coordinate location provided by simultaneous signals from particular coordinates. Specifically, two plus polarity signals indicate that the object is in the upper left quadrant of the overlapping sub-volumes, whereas two minus polarity signals indicate that the object is in the lower right quadrant of the overlapping sub-volumes. On the other hand, a minus polarity signal from the first detector 66, when arriving with a plus polarity signal from the second detector 68, indicates that the object is in the upper right quadrant, and so on. It will readily be appreciated that the principles advanced herein can be applied to arrays greater than 2x2.

For instance, Figure 6 shows IR detection means for a PIR sensor 80 that includes first and second eight-element detectors 82, 84 that, except for the number of elements, is substantially identical to the sensor 64 shown in Figure 5. As was the case for the sensor 64, for the sensor 80 shown in Figure 6 the sub-volumes of the detectors 82, 84 are optically superposed so that the respective monitored sub-volumes occupy the same space to render the virtual composite detector 86 shown in the functional diagram.

Both sensors 64, 80 shown in Figures 5 and 6 provide two simultaneous signals ("x" and "y" in Cartesian coordinates) as a moving object 12 moves through the monitored sub-volumes. The object 12 will activate one coordinate in each detector at a time, so that by taking the "x" and "y" signals together, the location of the object 12 can be determined. It will readily be appreciated that the sensor 80 shown in Figure 6 has higher resolution than the sensor 64 shown in Figure 5. Still further, if the polarity of the signals is taken

into account, additional positional resolution can be obtained, in accordance with principles discussed above.

Both sensors 64, 80 shown in Figures 5 and 6 can use an optics system 14 that optically scales human-shape images such that when the object 12 is a human, signals from two or more (x,y) locations in the array will be generated at once, whereas smaller objects such as animals, would induce simultaneous signals from fewer (x,y) locations. In this way, the number of array locations from which signals are simultaneously received can be correlated to an object size, to discriminate, e.g., pets from humans and cause an alarm to be activated only in the presence of the latter, or to open a door only in the presence of the latter, etc.

Figure 7 shows that the dual frequency concept of the sensors shown in Figures 2 and 3 can be combined with the two-dimensional array concept of the sensors shown in Figures 5 and 6 both to discriminate moving objects from non-moving objects on the basis of the number of frequencies received, and to determine direction of motion, and to discriminate among moving objects on the basis of size (number of array points simultaneously activated). Specifically, IR detection means for a sensor 88 can include a first detector 90 having elements 91 of one size and a second detector 92 having elements 93 of a different (in this case, larger) size, such that the frequency of the signals generated by the first detector 90 is different from the frequency of the signals generated by the second detector 92 for moving objects. Essentially, as shown by the virtual composite detector 94 in the functional diagram, the sensor 88 establishes a 2 x 2 array of monitored sub-volumes that is created by optical superposition of the sub-volumes monitored by the detectors 90, 92. The larger detector elements 93 establish an "x" coordinate by polarity, i.e., as shown a signal from the negative polarity element indicates a rightward "x" coordinate while a signal from the positive polarity element 93 indicates a leftward "x" coordinate. A motion-caused signal from each element of the array is identifiable as the simultaneous occurrence of wave peaks from an x-axis element along with twice as many wave peaks (i.e. occurring at twice the frequency) from a y-axis element.

Figure 8 shows yet another IR detection means for a sensor 96 that includes a first detector 98 having two rows of two dual-polarity element pairs 100 wired along the x-axis

to produce signals representing "y" coordinates and a second detector 102 having two rows of single dual-polarity element pairs 104 wired along the y-axis to produce signals representing "x" coordinates. The element pairs 100 of the first detector 98 are smaller than the element pairs 104 of the second detector 102, such that the frequency of the signals generated by the first detector 98 is different from the frequency of the signals generated by the second detector 102 for moving objects. The monitored sub-volumes are optically superposed to establish the virtual composite detector 106 shown in the functional diagram. This two-dimensional detector array provides greater position resolution than the sensor 88 shown in Figure 7.

Figure 9 illustrates IR detection means for a sensor 108 that is in all essential respects identical to the sensor 64 shown in Figure 5, in that it has first and second detectors 110, 112 having respective elements 114, 116 of equal size and orthogonal wiring, except that the sensor 108 shown in Figure 9 has eight dual-polarity element pairs per detector. The elements 114 of the first detector 110 are arranged in two vertical rows that are wired in the y-dimension by connecting the minus polarity element of a pair to the positive polarity element of the pair immediately below. On the other hand, the elements 116 of the second detector 112 are arranged in two horizontal rows that are wired in the x-dimension by connecting the minus polarity element of a pair to the positive polarity element of the pair immediately to the left. As indicated by the schematic symbol diagram, the y-dimension wired element pairs 114 of the first detector 110 provide x-dimension position information, while the x-dimension wired element pairs 116 of the second detector 112 provide y-dimension position information. To find position information, as illustrated by the virtual composite detector 118 in the functional diagram, the position of the object is indicated as in quadrant 119 in two-dimensional space ($x=1, y=2$) from which signals are simultaneously received, and as the point 120 by signal polarities ($x=plus, y=minus$). Also, moving objects are discriminated from non-moving interfering light by observing the sequential activation of points in the virtual composite detector 118.

Now referring to Figure 10, an exemplary logic flow chart for using different frequencies from the sensors shown in Figures 2, 3, 7, and 8 can be seen. Commencing at block 122, signals from the two detectors are received in, e.g., a clock cycle. Moving

to decision diamond 124 it is determined whether the signals are of two different frequencies and, if desired, whether the first peak of the signal from the first detector temporally coincides with the maximum slope of the signal from the second detector. Peaks and slopes can also be compared if desired for matching within user-defined criteria. If two frequencies are detected and, if desired, the peaks/slopes coincide in time and/or the peaks and slopes match defined criteria, "moving object" is output at state 126. Otherwise, "no moving object" is output at state 128.

It is to be understood that by "frequency" is meant not only the frequency of a sinusoidal-shaped signal that is typically generated when an object moves in a single direction at a constant speed across the monitored sub-volumes, but also the frequency of non-sinusoidal shaped or semi-sinusoidal shaped signals that essentially appear as pulses when, e.g., a person randomly moves in various directions and at various speeds through the monitored sub-volumes. In the latter case, more pulses per unit time, whether sinusoidal-shaped or not, are generated by the detector having the closer center-to-center element spacing than the number of pulses per unit time generated by the detector having the greater center-to-center element spacing. "Frequency" thus encompasses pulses or peaks per unit time.

Figure 11 shows the logic by which signals from the two-dimensional sensors shown in Figures 5-9 may be used to determine whether an object is moving. The signals from the two detectors of a sensor are received at block 130, and by determining, at decision diamond 132, that the coordinates of an object have changed within, e.g., a predetermined period of time, movement is indicated at block 136. Otherwise, no movement is indicated at block 134 and the logic loops back to block 130.

In addition to determining motion, the logic, for certain of the sensors disclosed herein, may proceed to decision diamond 130 to determine whether at least a threshold number of coordinates are active at once. In other words, it is determined whether a threshold number of signals are simultaneously received from plural elements of the detectors, indicating a moving object that equals or exceeds a predetermined size. Generally, larger moving objects are human in response to whom it is typically desired to activate the alarm, open a door, or take some other action, whereas smaller moving objects

typically are pets for whom no action generally is to be taken. Accordingly, for a larger object as determined at decision diamond 138, the logic moves to block 140 to indicate "target object" and, e.g., activate the alarm 22. On the other hand, if the object is not of sufficiently large size, no action will be taken.

Block 142 further indicates that the polarity of the signals can be used as discussed above to determine the direction of motion, regardless of object size if desired. In some cases it might be desirable to take action (such as activating the alarm 22 or opening a door) not just in the presence of a large moving object, but in the presence of a large moving object that is moving in a predetermined direction. Under these conditions, a signal might be generated indicating some predetermined action to be taken only after the determination at block 142 indicates that a large moving object is indeed moving in the predetermined direction.

It may now be appreciated that the sensors discussed above discriminate interfering white light from moving objects, as well as, in certain embodiments, discriminate moving objects from each other essentially based on object size. Also, one or more of the sensors discussed above can provide rough determinations of direction of object motion.

Now referring to Figures 12 and 13, a sensor is shown, generally designated 200, that can be used as the PIR detection system 16 shown in Figure 1. As shown, the sensor 200 includes at least two and in some implementations only two detector elements, each of which may have, in some implementations, two and only two parts, namely, a positive and negative part. If desired, all four parts may be of equal size and shape to each other. Each element generates a respective signal.

More specifically, in the non-limiting embodiment shown the above-mentioned detector element parts are arranged on a substrate in the following order, from left to right: a positive part 202 of a first element, a positive part 204 of the second element, a negative part 206 of the second element, and a negative part 208 of the first element, with the parts of an element being electrically connected to each other and disposed on a substrate 210. That is, the right-most positive part 204 and the left-most negative part 206 establish a first detector element, while the left-most positive part 202 and the right-most negative part 208 establish a second detector element. In any case, in the illustrative implementation shown

the positive parts 202, 204 are physically next to each other without any negative parts intervening and the negative parts 206, 208 are physically next to each other without any positive parts intervening. As was the case with the prior sensors, the first detector element shown in Figure 12 monitors a first volume of space that, if desired, at least partially may be optically interposed or superposed with a second volume of space monitored by the second detector element. The substrate 210 with both elements may be held in a single detector housing. In the non-limiting embodiment shown the two volumes of space are interleaved, or "interposed", although other implementations can use the superposition principles set forth above.

Figure 12 also shows, in addition to the element view, a schematic symbol and a functional diagram of the sensor 200, as well as a human-shaped image. The sensor 200 thus has two sets of elements, and when placed behind compound optics, produces two separate signals in response to images passing over the detector due to moving objects passing through the fields-at-view of the compound optics.

This can better be appreciated in reference to Figure 13, which shows, in part (a), the signals produced by the two detector elements (labelled "1" and "2" in Figure 13) in the presence of a moving object and, in part (b), the signals that are produced in the presence of non-moving stimuli such as white light. It is to be understood that a system that might include one or both of the signal processing circuit 18 and processing system 20 shown in Figure 1 can be used to execute the following processing.

As can be appreciated in part (a) of Figure 13, the signals from the two detector elements are added together to produce a sum signal 212. Also, the difference between the signals is rendered to produce a difference signal 214. To produce the difference signal, the individual detector element signals may be added together with the polarity of one of the signals reversed with respect to the signal baseline, thus effectively subtracting one signal from the other.

In the case of a moving object stimulus (part (a) of Figure 13), it can readily be appreciated that the "sum" signal 212 is of a different frequency than the "difference" signal 214. In contrast, in part (b) (when the detector elements are stimulated by non-moving stimuli), the frequency of the "sum" signal 212 is the same as the frequency of the

"difference" signal 214, albeit the "sum" and "difference" signals have different amplitudes. The processing system thus can correlate the frequency information to whether a moving object has been detected, and if so, output a detection signal and/or alarm so indicating.

Accordingly, the signal processing system associated with the sensor 200 can better discriminate between true motion and other signals. In the case of white light, and in the cases of several other detector-interfering stimuli, this improved detector offers dramatic reduction of false alarm probability.

Figure 14 shows an alternate system 300 having two or more PIR detectors 302, 304 (only two shown for clarity) in a single housing and receiving light from one or more respective optical elements 306, 308, with a detector and associated optical element establishing a detection member. The detectors send signals to processing circuitry 310 that may include amplification circuitry, and a processor 312 processes the signals to determine whether to activate an audible or visual alarm 314. The signal processing may be accomplished in accordance with disclosure above or in accordance with the above-referenced '250 patent, and the optical portion of the system 300 may be substantially identical to that shown in the '250 patent, with the following exceptions. The optical elements 306, 308 may be Fresnel lenses but they are configured such that no vertical dead space exists between any two adjacent monitored volumes, as shown in Figure 15, in which volumes 302a are monitored by the detection member that includes the detector 302 and volumes 304a are monitored by the detection member that includes the detector 304. Also, for the embodiments shown in Figures 16-18 motion is interpreted by the processing circuitry based on the simultaneous reception of different frequencies from the detectors 302, 304 in accordance with disclosure above. Fresnel lenses yielding the dead zones of the '250 patent less optimally may be used in connection with the present frequency-based motion discrimination principles.

With the structure of the alternate motion sensor 300 in mind, attention is now turned to Figures 16-21, showing various embodiments of the detection members. In Figure 16, a first detection member 316 includes one optical element with a detector having two elements, one positive and one negative, as shown defining a first spacing S1 between them. A second detection member 318 includes one optical element with a detector having

four detector elements alternating positive and negative defining a second spacing S2 between adjacent detector elements as shown. In the embodiment shown in Figure 16, the size of each detector element of the first detection member 316 may be larger than the size of each detector element of the second detection member 318, and/or the spacing S1 may not be equal to the spacing S2. The focal lengths of the associated optical elements can be equal. A moving object causes the detection members 316, 318 to generate signals of different frequencies from each other, which frequency difference is interpreted as motion by the processing circuitry, whereas a stationary stimulus causes the detection members to output the same frequency. Size discrimination is also possible using information from the volumes 302a, 304a, e.g., a small moving object might substantially occupy only one volume at a time, stimulating one detector much more than the other detector and thus indicating its smallness, whereas a large moving object would fill more than one volume at a time and hence stimulate both detection members simultaneously.

Figure 17 shows a first detection member 320 that includes one optical element with a detector having two detector elements, one positive and one negative, and a second detection member 322 that includes two optical elements with a detector having two detector elements that, because of the two optical elements, appear in the functional diagram as four monitored sub-volumes as shown, alternating positive and negative. In the embodiment shown in Figure 17, the size of each detector element of the first detection member 320 may be the same as the size of each detector element of the second detection member 322, and the spacing between detector elements of the first detection member 320 may be equal to that between detector elements of the second detection member 322, but the focal lengths of the associated optical elements are unequal, e.g., by a factor of two, causing the functional diagram to depict the monitored sub-volumes of the first detection member 320 as being larger than those of the second detection member 322. As was the case with the detection members of Figure 16, in Figure 17 motion is indicated by different frequencies from the detection members, and size discrimination may be implemented.

Figure 18 shows a first detection member 324 that includes two optical elements and a detector having two detector elements, appearing in the functional diagram as four monitored sub-volumes, as depicted in the top row alternating positive and negative. Also,

a second detection member 326, shown in the bottom row, includes four optical elements that cause one positive detector element and one negative detector element to appear in the functional diagram as eight monitored sub-volumes, alternating positive and negative. In the embodiment shown in Figure 18, the size of each detector element of the first detection member 324 may be the same as the size of each detector element of the second detection member 326, but unequal spacing is used for motion discrimination. Specifically, either the spacing between the two detector elements of the first detection member 324 is different from the spacing between adjacent detector elements of the second detection member 326, or the spacing between lens elements of the Fresnel lens associated with the first detection member 324 is different from the spacing between lens elements of the Fresnel lens associated with the second detection member 326, meaning that in practical applications the optical elements have unequal numbers of lens elements. A moving object produces a first number of signal peaks per unit time from the first detection member 324 and a second number of signal peaks per unit time from the second detection member 326, with the first and second numbers being different and on that basis indicating a moving object - essentially, once again producing different frequencies for a moving object. Size discrimination may be implemented.

Figures 19-21 show various sensor embodiments, including some that less optimally may not produce different frequencies to indicate motion yet that do support size discrimination. In Figure 19, a first detection member 328 includes one optical element with detector having positive and negative detector elements and a second detection member 330 with one optical element with a detector having positive and negative detector elements, with all detector elements being of equal size and spacing and with equal lens systems that do not necessarily produce the dead zones of the '250 patent. Size discrimination can be undertaken in accordance with above principles without vertical dead zones. When the detector elements are wired as shown in "schematic 1" of Figure 19 and arranged so as to create an array of monitored sub-volumes as depicted in "functional diagram 1", no dual frequency operation results for moving objects. On the other hand, the detector elements can be wired and arranged as indicated in Figure 13 discussed above to produce "schematic

2" and "functional diagram 2", in which motion detection is indicated in the presence of different frequencies from the two detection members.

Figure 20 shows a first detection member 332 that includes one optical element with a detector having two positive and two negative detector elements and a second detection member 334 with one optical element with a detector having two positive and two negative detector elements, with all detector elements being of equal size and spacing, and with equal lens systems that do not necessarily produce the dead zones of the '250 patent. Size discrimination can be undertaken in accordance with above principles without vertical dead zones.

Figure 21 shows a first detection member 336 that includes one optical element with a detector having four positive and four negative detector elements and a second detection member 338 with one optical element with a detector having four positive and four negative detector elements, with all detector elements being of equal size and spacing and with equal lens systems that do not necessarily produce the dead zones of the '250 patent. Size discrimination can be undertaken in accordance with above principles without vertical dead zones. The eight-element detectors yield 4 x 4 resolution. When the detector elements are wired as shown in "schematic 1" of Figure 21 and arranged so as to create an array of monitored sub-volumes as depicted in "functional diagram 1", no dual frequency operation results for moving objects. On the other hand, the detector elements can be wired and arranged as indicated in Figure 13 discussed above to produce "schematic 2" and "functional diagram 2" in Figure 21, in which motion detection is indicated in the presence of different frequencies from the two detection members.

It is to be understood that for the embodiments shown in Figures 14-21, the detection members are depicted in their basic unit form, and that they can be multiplied by placing multiple first detection members side by side vertically and/or horizontally and/or otherwise, to increase the field of view. Detector element spacing shown in the functional diagrams are for illustration only, it being understood that spacing between parts does not necessarily imply the presence of dead zones.

While the particular IMPROVED PIR MOTION SENSOR as herein shown and described in detail is fully capable of attaining the above-described objects of the invention,

it is to be understood that it is the presently preferred embodiment of the present invention and is thus representative of the subject matter which is broadly contemplated by the present invention, and that the scope of the present invention is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more". Moreover, it is not necessary for a device or method to address each and every problem sought to be solved by the present invention, for it to be encompassed by the present claims. Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase "means for" or, in the case of a method claim, the element is recited as a "step" instead of an "act". Absent express definitions herein, claim terms are to be given all ordinary and accustomed meanings that are not irreconcilable with the present specification and file history.

WHAT IS CLAIMED IS:

1. A PIR motion sensor comprising:
at least first and second infrared detection members (302/306, 304/308, 316, 318, 320, 322, 324, 328, 330, 332, 334, 336, 338), each detection member including at least one optical element and at least one detector with at least positive and negative detector elements, wherein:

the optical elements cooperate to establish four or more monitored spatial volumes substantially without any unmonitored vertical dead space between any two adjacent volumes established by the optical elements, the first detection member monitoring first volumes and the second detection member monitoring second volumes, the first and second volumes alternating in sequence.

2. The sensor of Claim 1, wherein a moving object causes the detector of the first detection member to output a signal having a frequency that is different from an output of the detector of the second detection member, and a non-moving stimulus causes both detectors to output the same frequency.

3. The sensor of Claim 2, wherein at least one detector element of the first detection member (316) has a different size than at least one detector element of the second detection member (318).

4. The sensor of Claim 2, wherein a spacing between adjacent detector elements of the first detection member (316, 324) is different from a spacing between adjacent detector elements of the second detection member (318, 326).

5. The sensor of Claim 3, wherein a spacing between adjacent detector elements of the first detection member (316) is different from a spacing between adjacent detector elements of the second detection member (318).

6. The sensor of Claim 2, wherein the focal length of the optical element of the first detection member (320) is different from the focal length of the optical element of the second detection member (322).

7. The sensor of Claim 2, wherein a number of lens elements of the optical element of the first detection member (324) is different from a number of lens elements of the optical element of the second detection member (326).
8. A PIR motion sensor (200) comprising:
 - at least one infrared detector having at least first and second elements (202/208, 204/206) generating respective first and second signals; and
 - a system (20) adding the first and second signals together to render a "sum" signal, the system also rendering a "difference signal" by subtracting one signal from the other signal, wherein the system outputs a detection signal representative of a moving object when the "sum" signal has a frequency different than that of the "difference" signal, and otherwise does not output the detection signal.
9. The sensor of Claim 8, wherein the first element (202/208) monitors a first volume of space that is at least partially optically interposed or superposed with a second volume of space monitored by the second element (204/206).
10. The sensor of Claim 8, wherein each element has two and only two respective parts (202/208, 204/206), one positive (202 or 204) and one negative (206 or 208), with the parts being of equal size with each other.
11. The sensor of Claim 10, wherein the positive parts (202, 204) are physically next to each other without any negative parts intervening and the negative parts (206, 208) are physically next to each other without any positive parts intervening.
12. The sensor of Claim 10, wherein the parts are arranged on a substrate in the following order: a positive part (202) of the first element, a positive part (204) of the second element, a negative part (206) of the second element, and a negative part (208) of the first element, the parts of an element being electrically connected to each other.
13. A method for discriminating a moving object in a monitored space from a non-moving object characterized by non-constant radiation, comprising:
 - providing first and second detector elements (202/208, 204/206) generating respective first and second signals;
 - adding the signals together to render a "sum" signal;
 - subtracting one signal from the other to render a "difference" signal; and

indicating a moving object if the "sum" signal has a frequency that is different from the frequency of the "difference" signal, and otherwise not indicating a moving object.

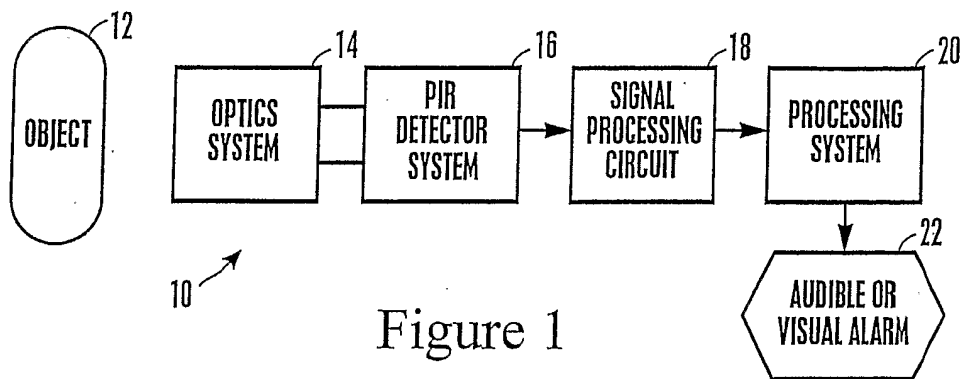


Figure 1

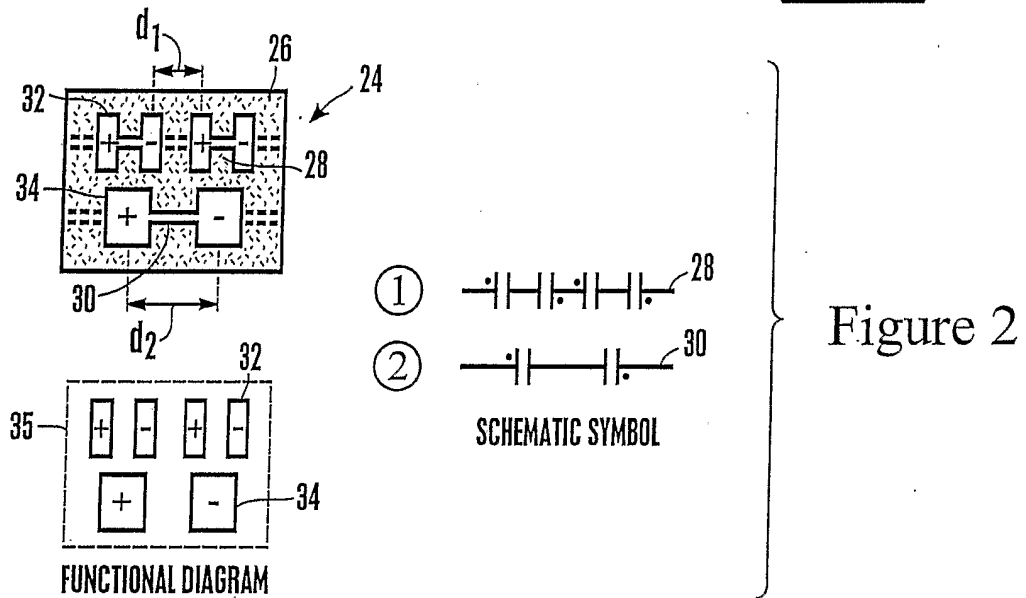


Figure 2

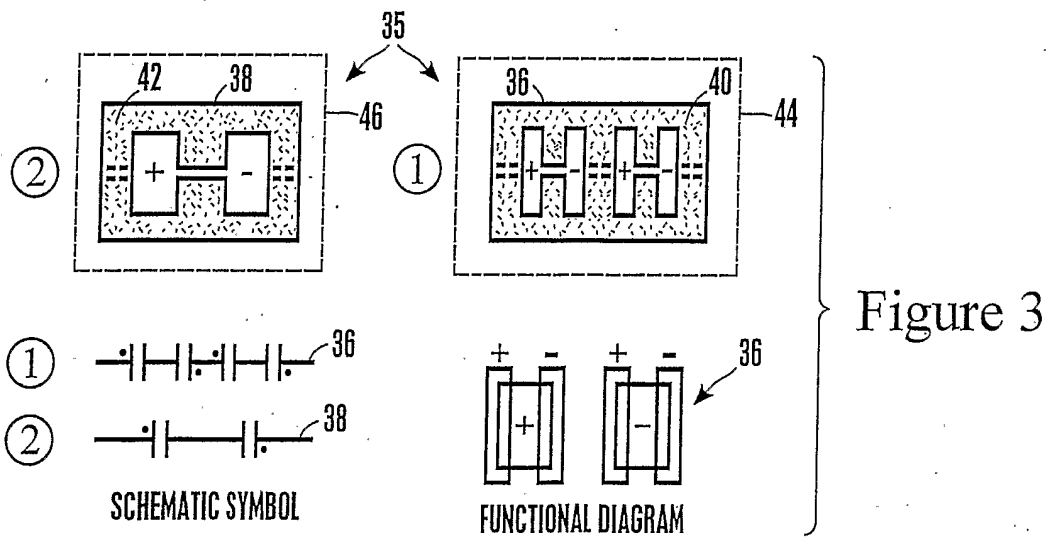
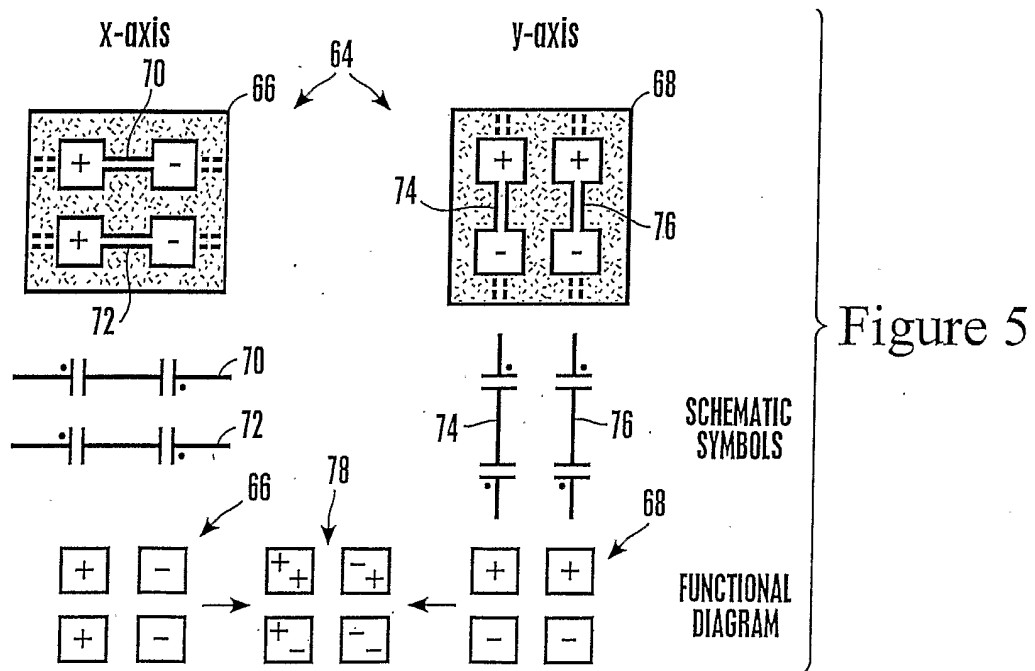
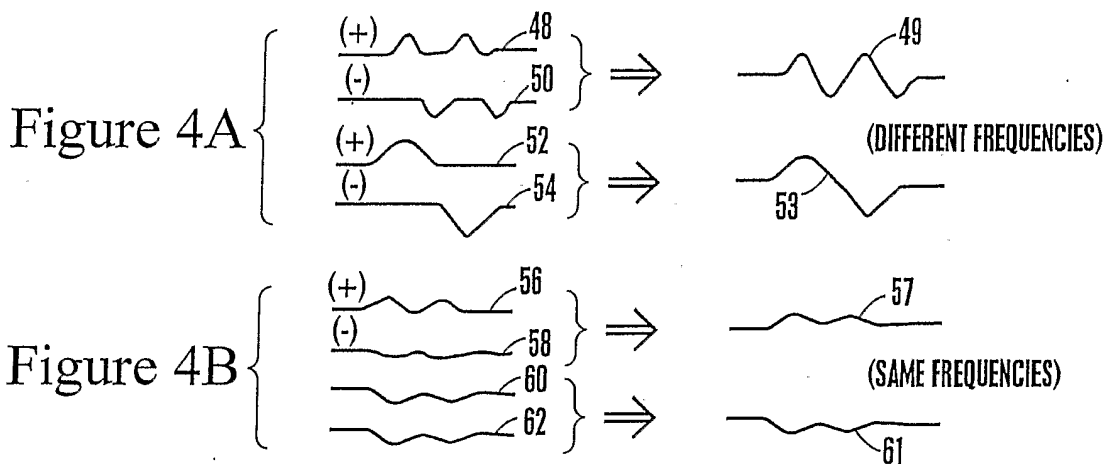
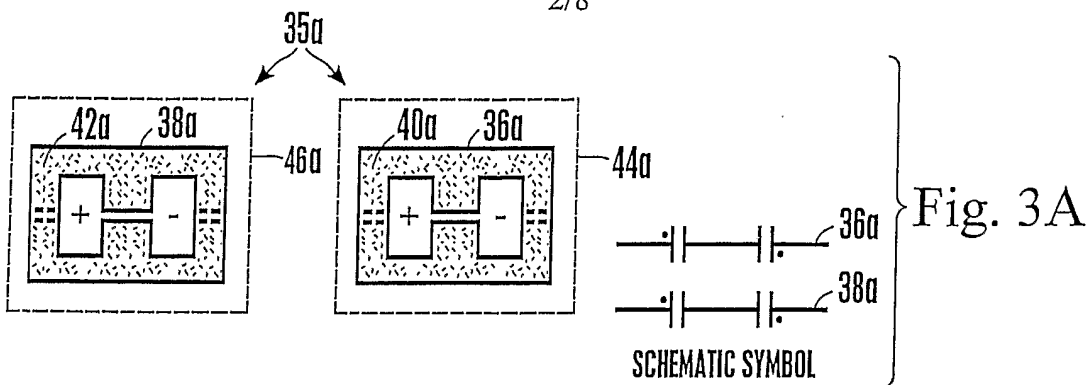


Figure 3



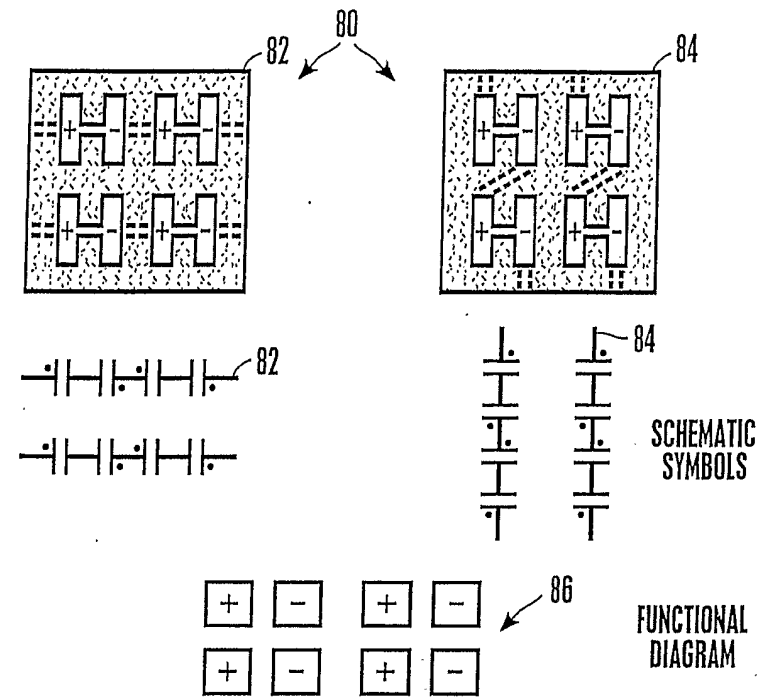


Figure 6

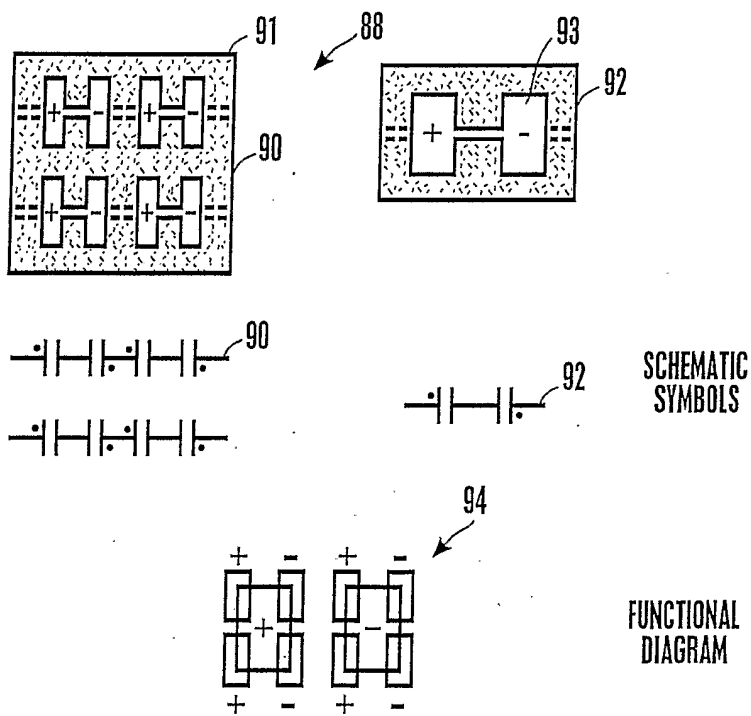


Figure 7

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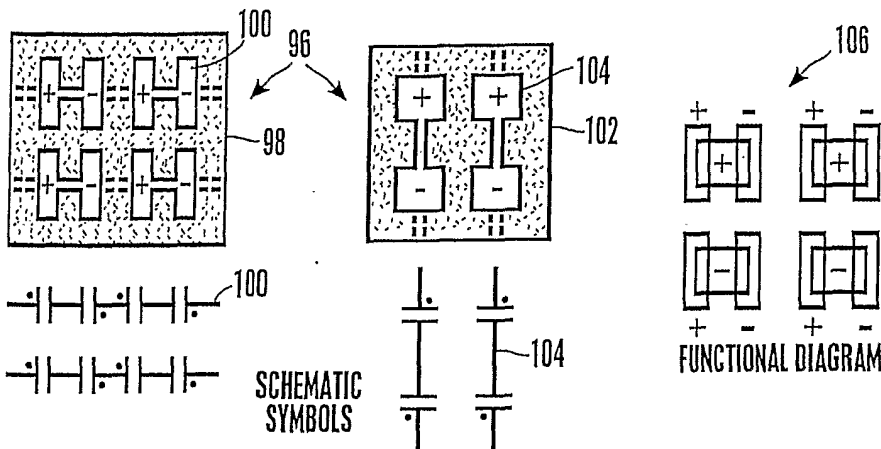
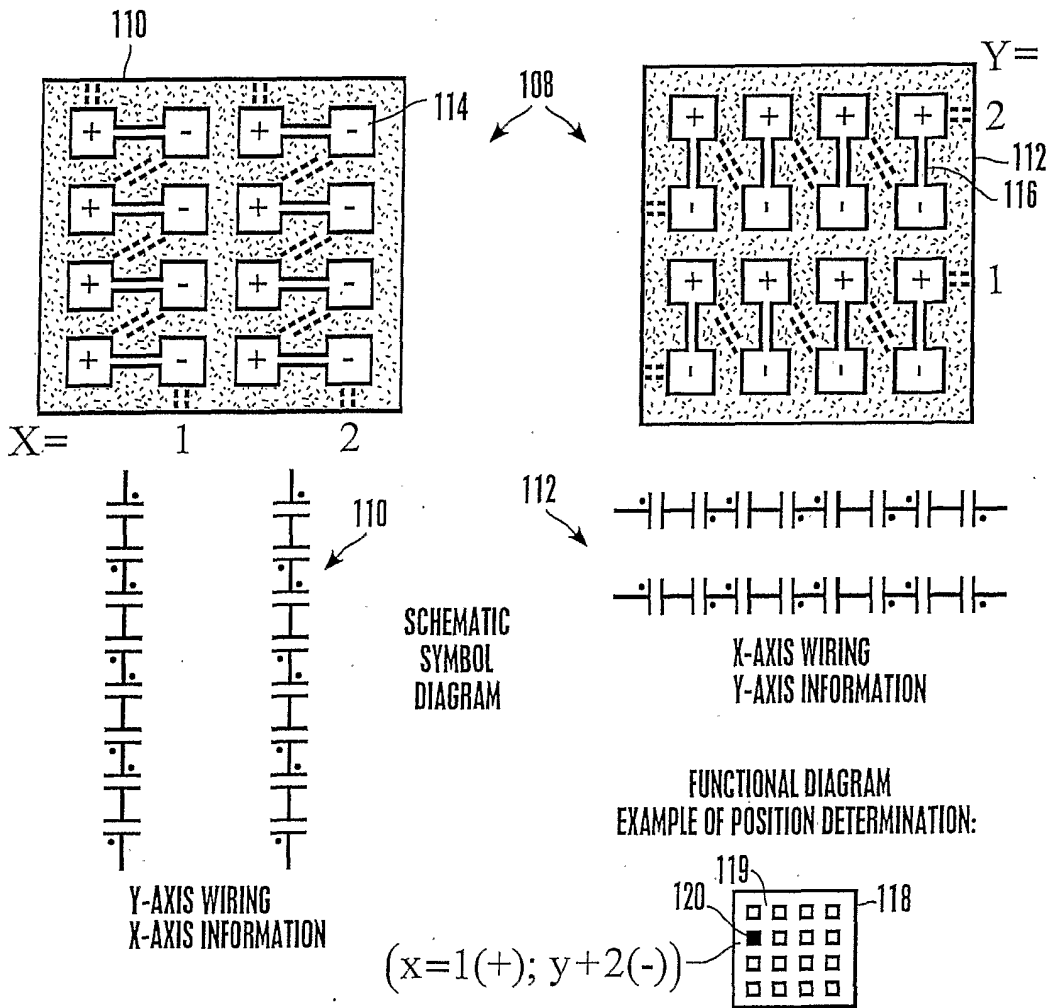


Figure 8

Figure 9



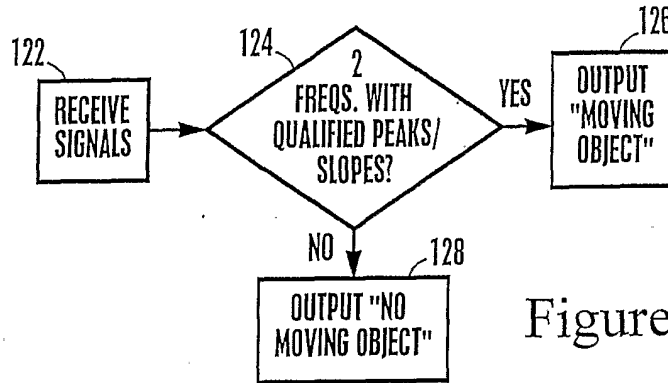


Figure 10

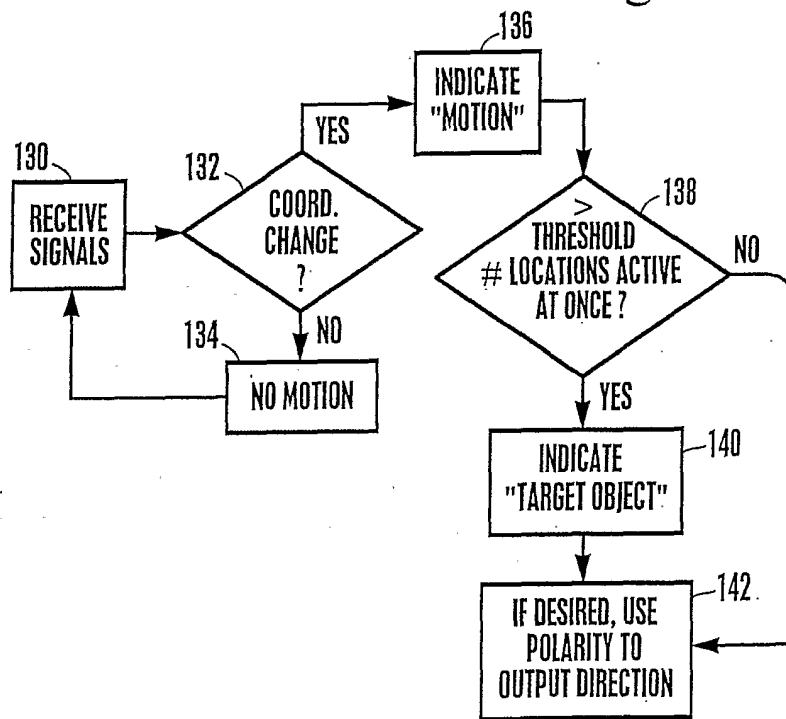
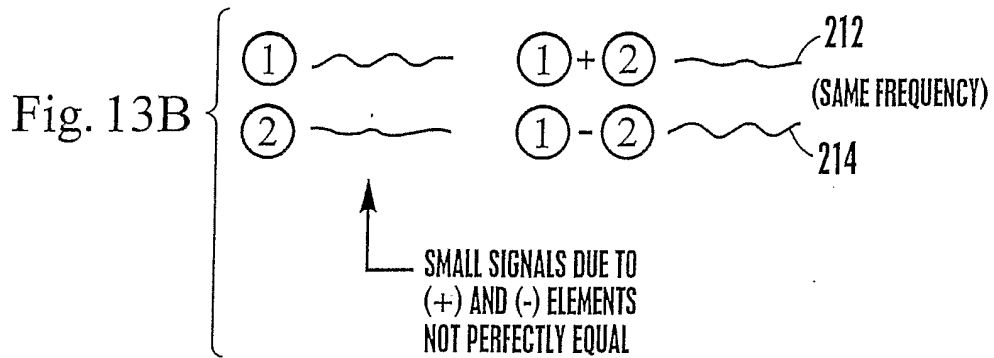
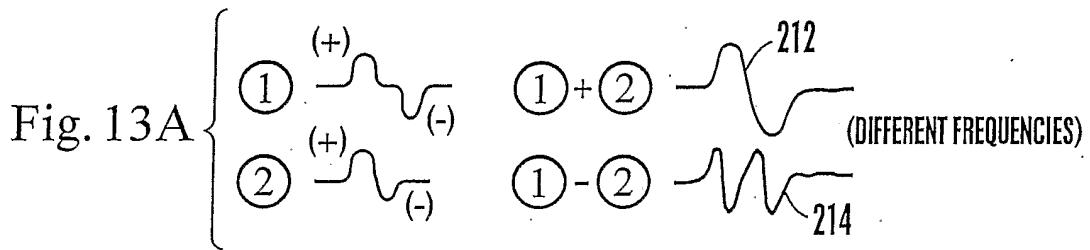
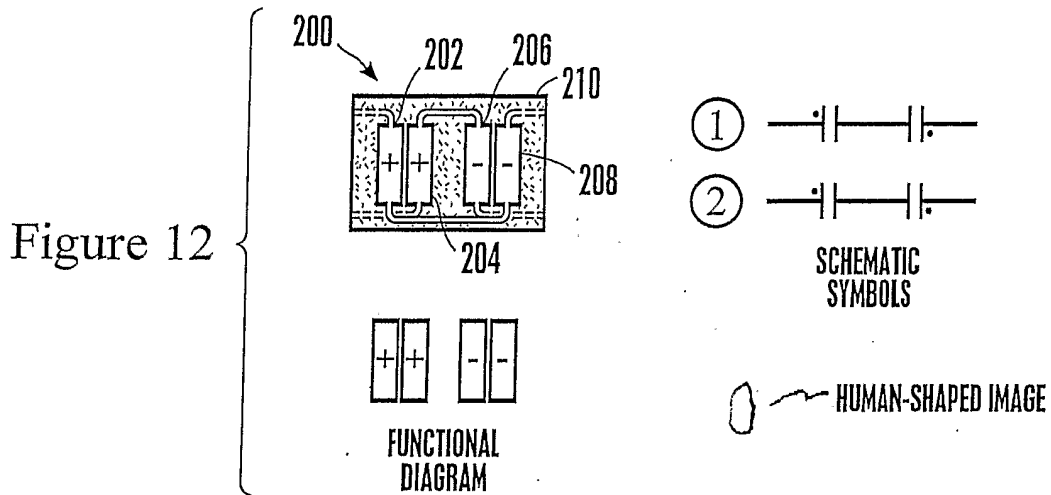


Figure 11



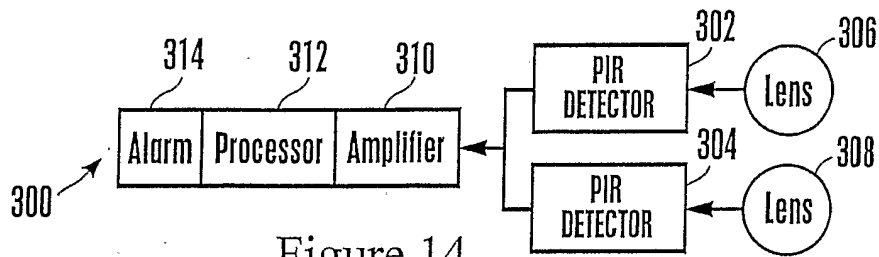


Figure 14

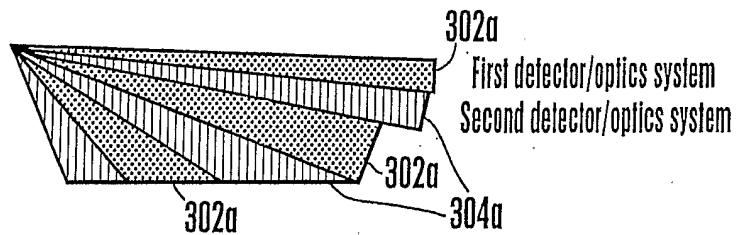


Figure 15

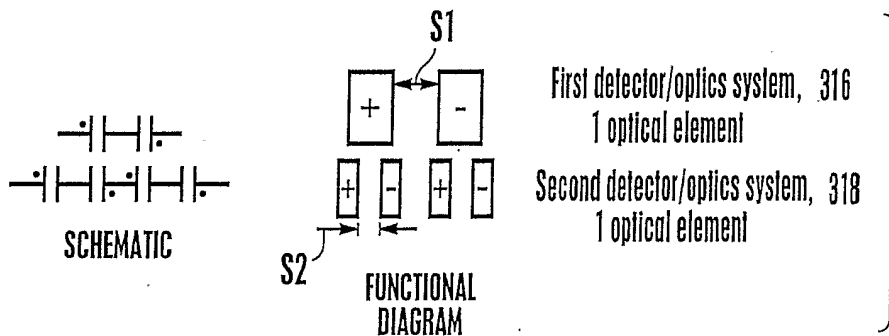


Figure 16

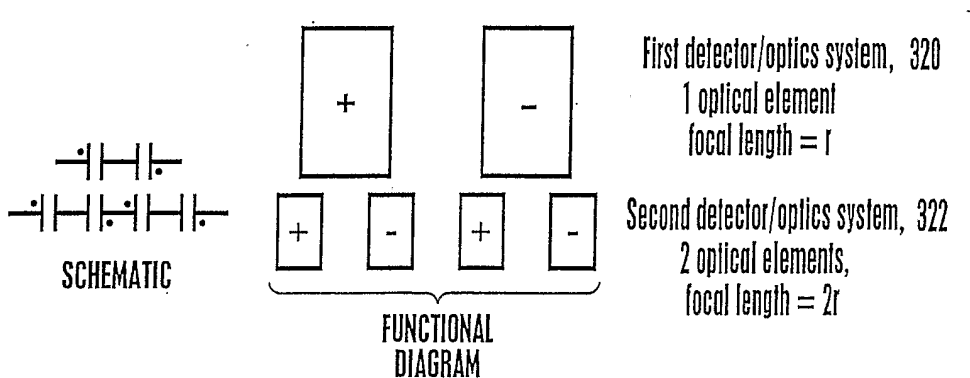


Figure 17

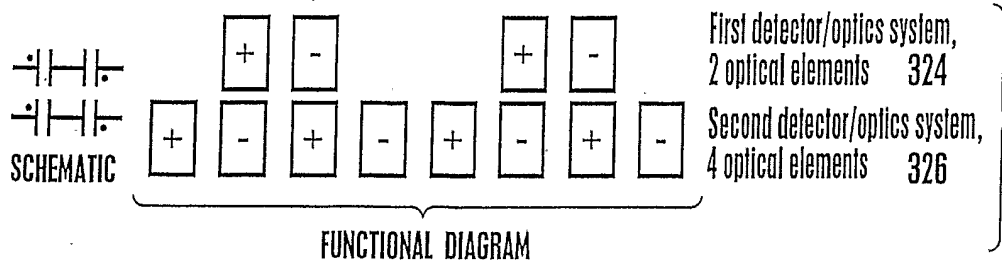


Figure 18

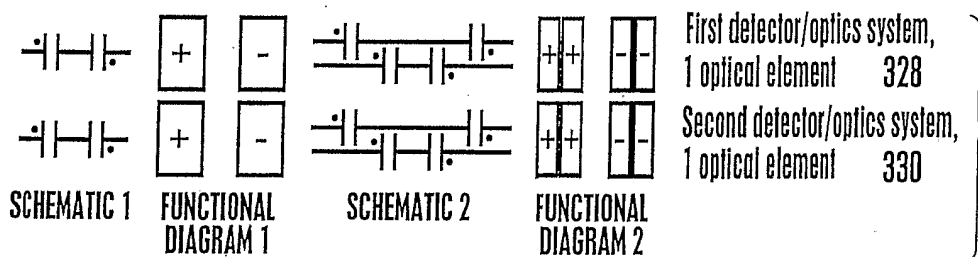


Figure 19

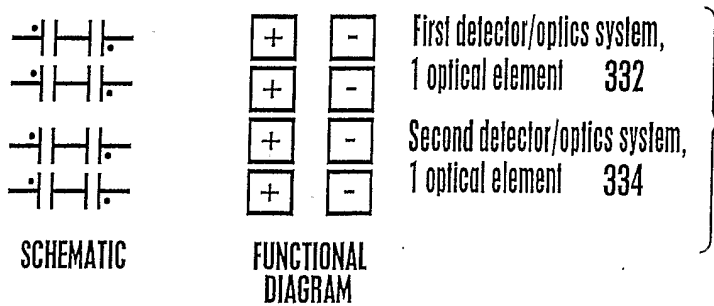


Figure 20

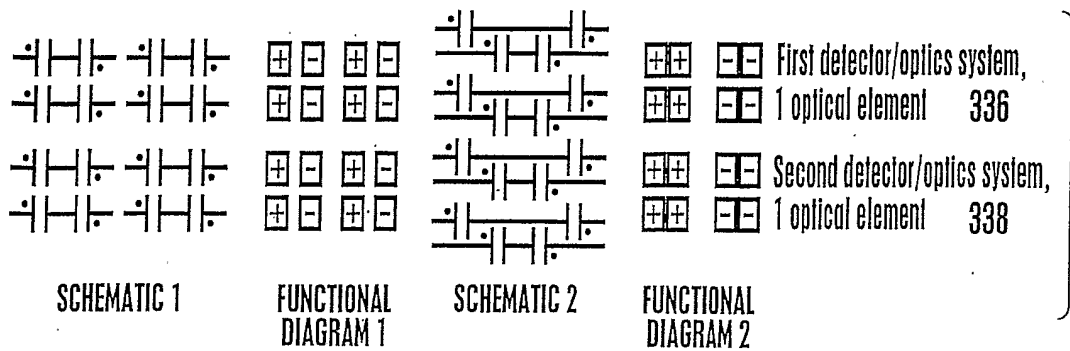


Figure 21